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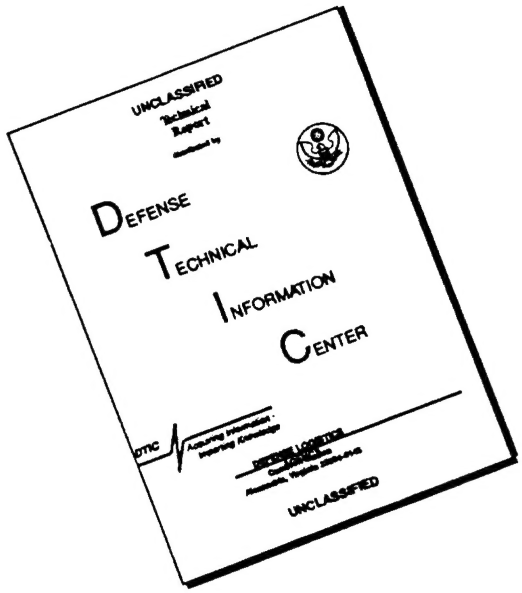

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FOR A PERIOD covering approximately the past 15 years, a large portion of the subsonic aerodynamic research and development conducted in this country and Europe has dealt with various aspects of the problem of producing an aircraft incorporating very short field landing and take-off capabilities with a cruising speed considerably higher than that obtainable from conventional helicopters.

Many schemes and configurations have been studied. Some have placed emphasis on high speed capabilities and hence have employed jet propulsion. Others, desiring higher efficiencies at the lower speeds, have made use of propellers or rotors. None has so far demonstrated such outstanding success that it clearly represents the most satisfactory solution to the problem. Moreover, at the present time no such machine has enjoyed more than limited production for evaluation purposes.

Fifteen years represents a relatively long development time. Does the failure to build more than a few experimental vehicles in this period indicate that this type of aircraft is impractical, that the technical problem is overly severe, or that the need for such a machine has not yet sufficiently developed so that a reasonable scale developmental program can be supported? It is the purpose of this paper to examine these questions critically in order to make concrete recommendations about the future direction of subsonic research within this country.

MATCHING THE WEAPON TO THE DEFENSE POLICY

Throughout the development of man and his institutions, speed has generally been considered a virtue, its desirability for the most part being unquestioned and accepted as a universal truth. Any element of a system that increased the speed of functioning was considered worthy of development. In many fields, particularly transportation, this search for speed has become a fetish, a faith to be followed blindly, to which almost no sacrifice is deemed excessive.

This is more true in military aviation than in any other field. Here, in each category of aircraft, unceasing efforts have been made to increase flight speeds. Helicopters, logistic aircraft, fighters, and bombers have undergone continuous development primarily aimed at pushing top speeds still higher and higher. It has become common to identify with high flight speeds both the ability to survive battlefield conditions and the tactical advantage of deploying great force against a given target in the shortest possible time.

Such identification is, like all generalities, only true within certain limits. Battlefield survivability is not greatly enhanced by speed if that speed has to be purchased at the price of extensive operating sites that can be easily spotted and attacked by the enemy. Tactical advantage is not greatly improved by speed of deployment if upon arriving at the target, the mission can't be carried out due to problems arising from adverse weather conditions, or because of difficult terrain.

In the broadest sense, the desire for high flight speeds in military operations is merely a reflection of the nation's desire to win as rapidly as possible whatever war in which it finds itself enmeshed. This desire has grown in intensity and significance since the end of World War II, largely due to the emergence of a world situation in which practically all

ABSTRACT

Viewed against the background of a defense policy which requires the nation to be prepared at any instant to mount military operations ranging from a mere show of force to all out nuclear war, the possible role of V/STOL aircraft in the military organization is examined. A number of potential missions are projected and analyzed in order to obtain an indication of the probable routes of development that will be followed. The still existing technical difficulties and the areas of required research and development are discussed with an eye to eliminating the gap between the initial, or exploratory research, and the final development of a weapons system.

nations fell into the sphere of influence of one of the two super states, the United States or the Soviet Union.

It has become more or less common practice to think and speak in terms of two entirely different types of war,the local brush fire or tactical war, and the total or strategic war. The local, or tactical war is conceived of as an action, limited by the mutual desire of the major protagonists to avoid the all-out conflagration, to given geographical locations, and to more or less conventional (non-nuclear) weapons. The strategic war is pictured as a cataclysmic holocaust of nuclear warheads borne by ballistic missiles.

Admitting the possibility of only two types of war is a dangerous oversimplification that can lead to an incorrect weapons development and procurement policy. The mere fact that the Korean conflict and the other struggles in the Near East and southwestern Asia have been confined to given areas and types of weapons is by no means a guarantee that this will be the case in the future.

If as major a conflict as that in Korea were to break out again, there seems little doubt that full tactical use would be made of nuclear warheads and at least relatively short range rocket missiles. Certainly, full use would be made of anti-aircraft and air-to-air missiles. In addition, it is not unlikely that great use would be made of reconnaissance satelites, which in combination with submarines, either loaned or "volunteered" by Russia, could make the oceans very unhealthy places indeed.

Although one hears a great deal about suddenly being projected into a major strategic conflict by accident, it would appear that the chances of this type of war developing as the gradual extention of a future Korean type action are even more likely. It therefore behooves this nation to be in a position to apply powerful forces of a nature appropriate to the situation as rapidly as possible after the decision to use force is reached. Only by the overwhelming application of such force can the trouble be stamped out before the dangerous drift toward all-out strategic war starts. Hesitation, indecision, delay in execution, lack of suitability of the types of forces and weapons employed, any of these, or, more probably, all of them to various degrees and in combination, can prove fatal.

The dual needs of speed of application and suitability of force have eliminated from the present scene adherence to what the economist refers to as defense in depth, the maintenance of minimal defensive forces and the building up of economic and manufacturing reserves with which to produce the products of war in time of national danger. As far as can currently be projected, speed of action having become such a controlling element, the future wars will have to be fought with the weapons on hand at their inception.

To be adequately prepared for appropriate action under such circumstances is, of course, vastly more difficult and costly than defense in depth. Striking forces of sufficient size and strength to produce the desired degree of local superiority must be deployed in such a manner that they can reach any potential trouble spot within a minimum period of time after the decision for action is taken. These forces must in turn be backed with quickly mobilized home forces that can be rapidly transported to support the striking force as required. Little time will be available to establish logistic support of these forces, which means that a flexible system capable of providing such support to any place on the globe must be maintained in a state of readiness at all times.

These are what may be termed tactical forces. They have to be prepared to meet and defeat any enemy ranging from spear carrying tribesmen to a highly trained military force employing the latest tactical weaponry including nuclear warheads. They, however, represent but a single portion of the nation's ready defence, for it can never be forgotten that irrespective of the tactical situation, all-out strategic warfare can begin the instant any of the potential protagonists feel that they have more to gain than to lose by such a struggle. Such a belief, if not actually produced is at least strengthened by a substantial technical advantage such as a high probability kill anti-missile system, or by a highly reliable delivery system that is either so powerful that it can be fired before any defending system could reach it, or can so baffle the defenses with decoys that a high percentage of the warheads will penetrate. The technical progress in such systems cannot be permitted to lag for an instant, and so the cost of defense grows.

There is no absolute scale by which the amount of defense per dollar can be measured, but it is certain that being forced into a situation in which the nation's defensive posture is shallow, (a situation in which we must constantly keep stockpiled the actual weapons and forces with which the war, or at least its critical phases, will be fought,) has vastly increased the total cost of the so-called peacetime military establishment. Although we do not as yet seem to be approaching a situation in which the percentage of the gross national product devoted to defense is reflected in a major curtailment of our standard of living, some economists are voicing grave concern about the future.

It seems obvious, therefore, that every effort should be expended toward extracting the highest utilization possible from each weapon system in the arsenal. From an economic point of view it would be highly desirable if we could concentrate on only one system, a ballistic missle for example. This would have the advantage not only of standardization, but since its strategic war mission would dictate a substantial size nuclear warhead, it would be capable of snuffing out small brush fire wars, probably with a single shot. It might further seem that the occasional use of such a weapon would serve to keep a check on its effectiveness as well as maintaining the launching crew in a high state of training.

The disadvantages of such a single weapon system are obvious. Quite apart from the appalling moral issues raised by the use of such a weapon for anything other than the most clearcut case of self-defense, there are the usual disadvantages of putting all the eggs in one basket. Although seemingly invincible today, what happens to the nation if an effective defense to its single weapon is found tomorrow? How would the other nations of the world, particularly those of the Soviet block, react to the use of such weapons as a

method of controlling a brush fire war in all probability created as a result of communist agitation? It would appear that the application of such a single weapon system to control an outbreak would lead to an immediate retaliation from the Soviet Union. and hence precipitate the very strategic war we wish to avoid.

The single massive weapon system solution is thus patently unsuited to providing the maximum defense for each dollar spent. To demonstrate the fluidity of the defense situation, however, it should not be overlooked that essentially just such a system was seriously contemplated by the nation's leaders only a few years ago. At the present time the spectrum of wars that might have to be fought, and political situations that might have to be faced, is so great that no one weapon or type of weapon can hope to be suitable for every case. Although we must strive to produce the overwhelming application of force at the time and place required by the situation, this force cannot be so overwhelming that we are afraid to use it.

If we cannot then concentrate on the development of a single all-purpose weapon, we can at least attempt to produce multipurpose capabilities within the families of weapons we are forced to utilize. By this, I mean we must attempt to develop devices that can be used effectively either against native guerrilla troops or against well trained and equipped tactical forces. Of particular interest in this respect are the various types of aircraft currently available or under development.

Although it is a matter of heated debate whether or not aircraft, or in fact any weapon besides the ballistic missile, has a significant role to play in an all out strategic war, it is certain that in lesser conflicts the airplane will be of paramount importance in the areas of establishing and maintaining air superiority, close ground support, logistic support, airborne assault, reconnaisance, and liaison. The particular role to be played by aircraft will depend upon the type of war being fought, the manned vehicle gradually giving way to unmanned missiles as the level of warring sophistication approaches the all-out strategic war.

The problem confronting the aeronautical engineer is how to extend the usefulness of military aircraft over the widest range of possible wartime conditions. In doing so he has applied the weapon systems approach, considering the aircraft as only one part of a complex system of maintenance, logistics, operating bases, electronics, and weaponry designed to exert, with the greatest possible level of probability, the greatest possible force at any given time and place.

GENERAL V/STOL AIRCRAFT CONSIDERATIONS

Such studies invariably lead to painful reassessments of established and strongly entrenched concepts as well as design criteria. Is speed really the factor to be sought after? Is there a mission, or more properly, a spectrum of missions, that can be performed more readily at extreme Mach numbers rather that at lower speeds? What sacrifices are required to obtain speed, and how do these sacrifices affect operation within a wartime environment? These, and other questions not unlike them, have caused many engineers to turn their eyes to the other end of the speed scale to see if improvements in the landing and take-off characteristics of airplanes might not hold a key to the extension of their military utility in light of the changing nature of defensive weapons and tactics.

The result has been a rash of vertical or short landing and take-off schemes, the so-called V/STOL aircraft. As so frequently happens, engineers and inventors have been so impressed with their own ideas, that wild claims of the rashest nature have been made for these devices. As also happens with equal frequency, other groups with interests that they feel will be jeopordized by the development of such machines have been scathing in their condemnation of either the aircraft or the manner in which it is proposed to use them. The result has been such a hornet's next of claims and counterclaims that the issue has become almost hopelessly beclouded, leaving the people charged with the responsibility of establishing a weapons procurement policy unable to separate fact from fiction and supposition from experimental evidence.

The situation has been nicely summarized by Dr. Robin Higham who, in his work "The British Rigid Airship, 1908-1931, A Study in Weapons Policy," observed that:

"Every new weapon has at least two enemies in addition to official conservatism; its rabid opponents and its violent enthusiasts. Both have vested interests to protect. The former ridicule it as expensive and useless, the latter see it as an almost universal panacea. Neither is, of course, right. Moreover, it must be recognized that the number of ideas submitted to the authorities is too often out of all proportion to those which do prove feasible. After any considerable deluge of these inventors' fantasies, officials become incapable of discrimination and are apt to regard all, except those which modify or amend somethin with which they are familiar, as the work of a lunatic."

This is by no means the best method of arriving at a weapons policy, but it is traditional. In spite of these difficulties, studies have proceeded into both the operation and engineering possibilities of V/STOL aircraft. To be effective, it is realized that the machines under consideration must be very carefully matched to each mission. A factor to be decided is whether or not the mission really requires vertical take-off abilities, or whether good short field characteristics are sufficient. Is top speed a factor? If so, how fast should the aircraft go? These and similar questions must be answered before an engineering solution can be attempted.

From the research already performed, a number of important points about these machines have emerged. The most significant is the magnitude of the penalty of vertical take-off. A machine designed to carry a given payload at a given speed over a given range may increase in size and weight anywhere between 1/3 and 1/2 times the weight of a conventional airplane performing the same job, if vertical take-off capabilities are required (Fig. 1).

The size and weight penalty varies with the top speed requirement of the machine. If its performance is such that to meet maximum level flight speeds it must have enough power installed to produce a thrust force of the same order as its weight, the VTOL penalty is much less than for a machine whose propulsive requirements are more modest. This has let to a number of investigations of methods of obtaining a better match between propulsion and lifting thrust by means of augmentors such as fans or ejectors.

Vertical take-off and landing presents additional problems in the area of stability and control as well as in overall reliability. As the flight speeds drop, the effectiveness of the aerodynamic surfaces diminishes until they are no longer capable of providing sufficient forces to insure adequate control response. Although the aircraft will probably display unstable characteristics under such low dynamic pressure conditions, it has been shown that it can be made to have acceptable handling characteristics, provided adequate control moments are provided from some auxillary source such as small jets or fans located at the extremities of the machine. The majority of the V/STOL aircraft that have achieved flying status have been equipped with autostabilization systems of one sort or another, but some have displayed adequate flying characteristics without such systems, an important simplification that will lead to increased ease of maintenance and hence reliability in the field.

Perhaps the most severe reliability problem arises from the fact that in the hovering and low speed flight regimes, the aircraft is being supported largely by the thrust of a propulsive system. Although the advent of the gas turbine has increased the reliability of aircraft engines well above that of the reciprocating engines, the possibility of an engine failure during a critical phase of the take-off or landing is a constant threat.

One solution to the problem is to overpower the machine so that even with the failure of one engine the remainder will be powerful enough to keep the plane airborne. To keep the penalty in installed weight and fuel as small as possible, this implies utilizing a power supply comprised of many small units so that the fractional duplication of thrust is minimized.

Another design approach is simply to consider the risk as being a military hazard that has to be accepted. In such designs, an engine loss may mean the total loss of thrust and control, but generally the thrust will be distributed among several units. After the failure of one engine, the remaining units may be insufficient to keep the vehicle airborne, but they will at least supply some thrust to slow the desent and to maintain positive control.

In this regard, the method of obtaining vertical thrust becomes of great significance. Fig. 2 demonstrates the trend of relative hovering efficiencies for various propulsion systems. The helicopter rotor, by moving large masses of air at relatively low velocities, achieves the highest thrust per unit of supplied power. The hovering efficiency (vertical lift per unit supplied power) falls off rapidly with increasing downwash velocities, being the lowest for jet devices which move relatively small masses of air at high velocities. Since the helicopter rotor is a source of drag and vibration at high speeds, the designer must thus compromise between his desire to hover efficiently and the requirement to obtain the highest possible flight speed.

The mission requirements really dictate this compromise. If the emphasis is placed on hovering, a typical mission involving extensive hovering or maneuvering at low speeds close to the ground, the most expedient design solution will be a helicopter or a close helicopter derivative, such as a tilting rotor. If, on the other hand, the emphasis is on speed and vertical thrust required just at the time of take-off and landing, then a higher exhaust velocity device such as a ducted fan or lifting turbojet might be used. Other factors such as the speed altitude profile of the mission and the desired endurance and range also affect the choice of lifting system.

This design compromise between hovering efficiency and speed is frequently a source of difficulty. The large mass flow, low induced velocity devices, such as the helicopter rotor, must generally, owing to their high drag, be eliminated if cruising speeds much in excess of 200 knots are desired. As a consequence, designers have gone to varieties of propellers and fans (Fig. 3) as a solution in the speed and altitude ranges between those effective for helicopters and those in which a turbojet machine seems most effective. Because of the size of these devices, necessitated by the large mass of air handled, they must be distributed about the airframe,

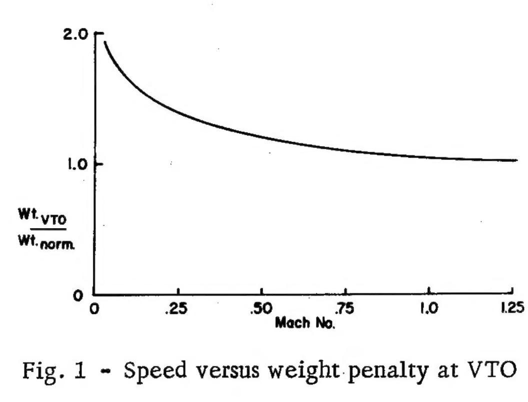

Fig. 1 - Speed versus weight penalty at VTO

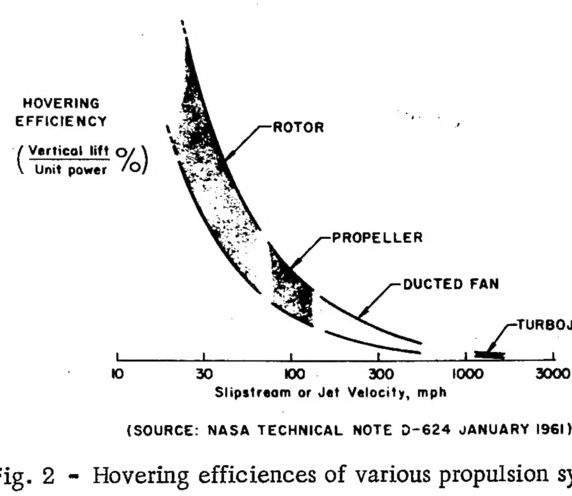

Fig. 2 - Hovering efficiences of various propulsion systems

consequently producing extreme moments in event of assymetric failure. These moments are generally too large to be handled by the control powers available at low speeds obtained either from small jets or control fans. Such designs must therefore encorporate highly reliable interconnection systems either by direct shafting or by forms of fluid coupling; for although a loss of thrust may be an acceptable risk, a catastrophic loss of control is not. As shown by Figs. 4, not all proposed jet powered configurations avoid this problem, but the possibilities of clustering all the lifting jets close to the c.g. or of utilizing units producing a relatively smaller percentage of the total thrust do, to a great extent, ease the design problem.

Irrespective of its type, every airplane is dependent upon the ground and ground facilities. The conventional military aircraft of the present require relatively extensive facilities generally including long paved runways or a catapult and arresting system. As minimum flight speeds approach hovering, the amount of space required for the take-off and landing decreases, but the dependance on the ground remains. Operating in close proximity of the ground can cause severe problems. These may be grouped under the two general headings of adverse aerodynamic ground effects and ingestion.

The first type of problem arises from the fact that the high velocity jet or slipstream of the lifting system by striking the ground is continued in a region below the aircraft. Depending upon the nature of the terrain, the wind velocity, the aircraft altitude, the downwash velocity, and the geometry of the lifting system, it may react in several different ways (Fig. 5). If it is a system of centrally located high ve-

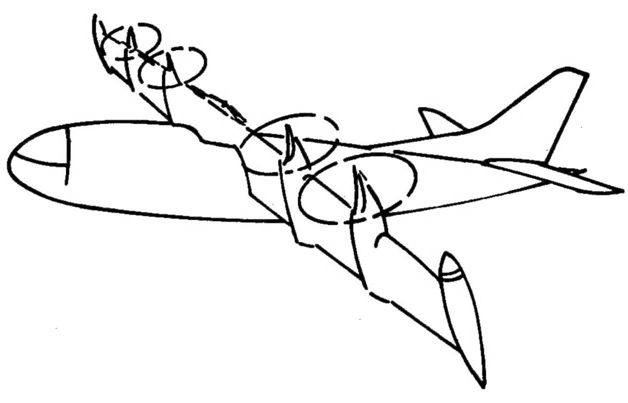

Fig. 3A - Tilt wing configuration

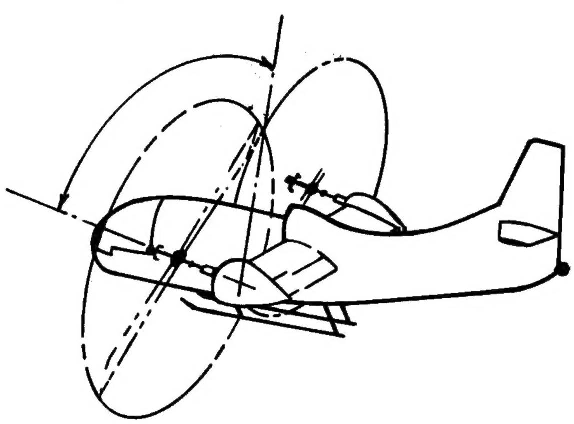

Fig. 3B - Tilt wing configuration

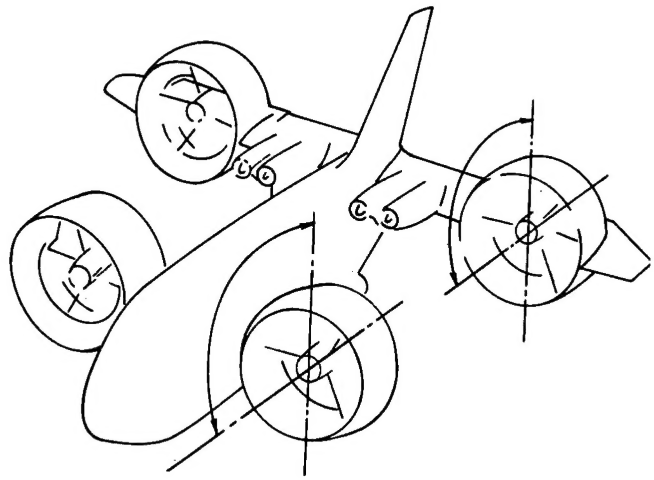

Fig. 3C - Tilting duct fan configuration

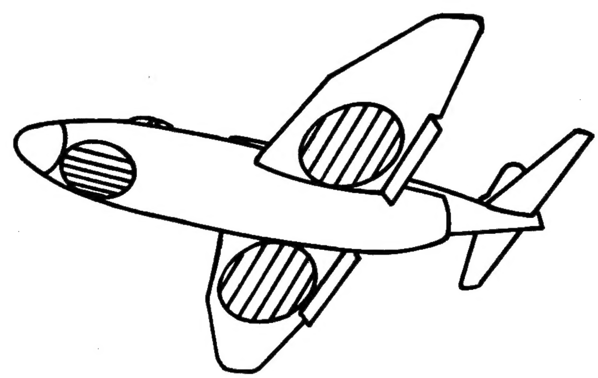

Fig. 3D - Ducted fan configuration

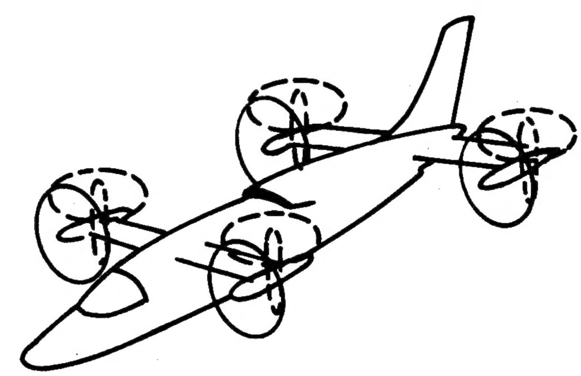

Fig. 3E - Tilting propeller configuration

locity jets issuing out from below the fuselage and wing, it will probably spread out over the ground like a three dimensional impingment flow, reducing lift by producing regions of high velocity and hence low pressure below the aircraft. By separating the jets, it is sometimes possible to produce a fountain like effect arising from their interaction, producing a strong upward effect by increasing the pressures on the under surfaces of the wing and fuselage. It has definite disadvantages in the form of a rising current of hot gasses frequently bearing with them sizable and possibly destructive bits of debris. An additional disadvantage is that the position of upflow impingement may change owing to wind, ground contours, or aircraft attitude, resulting in large, and at times abrupt changes in control moment requirements.

The term ingestion should correctly apply only to material swallowed directly into the intake of the propulsive system, but through common usage, it has come to cover roughly all the problems arising from the tendency of a jet or slipstream to kick up debris and hot gasses. These debris and gasses can form a serious hazard to ground personnel and installations close to the landing site. They can also damage the airframe and by obscuring the pilot's visibility seriously hamper his ability to maneuver his machine. Their most serious effects, however, are evidenced in the performance of the power plant.

The gas turbine has proven to be a far more reliable and rugged piece of machinery than anyone could possibly have imagined prior to its widespread introduction into commercial use. Although not particularly happy about indigestible material such as gravel, sand, and nuts and bolts, engines into which these materials have been introduced have continued to run for limited periods with only a slight loss of thrust. A much more serious problem, from the point of view of sudden loss of thrust if not from engine life, is posed by the recirculation of hot gasses. Fig. 6 demonstrates a typical variation of engine performance with inlet temperature. Quite clearly it is imperative that hot exhaust gasses be kept from reentering the engine inlets, even at the cost of foregoing the possibility of a favorable ground effect from the fountain effect.

MATCHING V/STOL AIRCRAFT TO THE MISSION

In light of the preceeding discussions of the defensive policies forced upon the nation, and the peculiar characteristics present to varying degrees in the different varities of V/STOL aircraft, it is informative to examine a spectrum of hypothetical tactical missions that might be expected to arise, in order to ascertain what role, if any, such aircraft might play, and to what degree the mission requirements will dictate their design characteristics.

It would appear that actually very few military missions will require a true vertical landing and take-off. Convenience of command and maintenance will require that numbers of aircraft, possibly squadrons or smaller groups, operate from the same base. This means that a large enough space must exist in which to park several such lines. Under these circumstances, it seems unlikely that there wouldn't be at least four or five wing span lengths of clear area that could be used as a runway. STOL operation would thus be possible with some resultant reduction of cost and complexity, the actual saving being a function of how closely the landing and take-off operations could approach those of conventional machines.

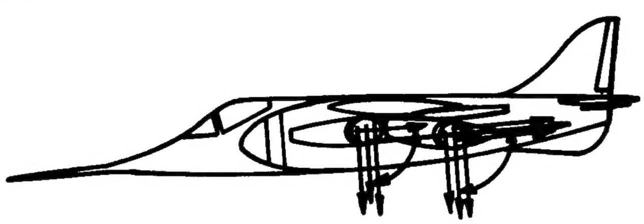

Fig. 4A - Deflected jet configuration

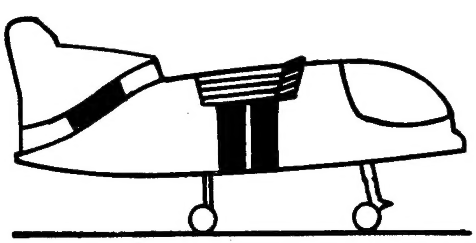

Fig. 4B - Deflected jet configuration

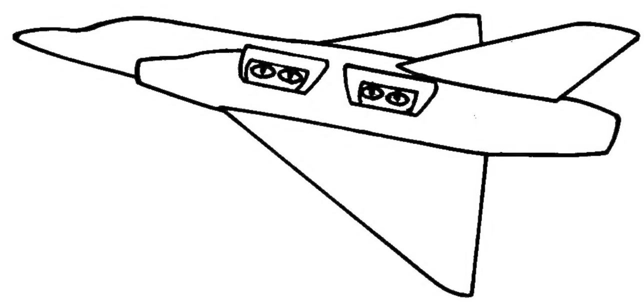

Fig. 4C - Clustered lifting jet configuration

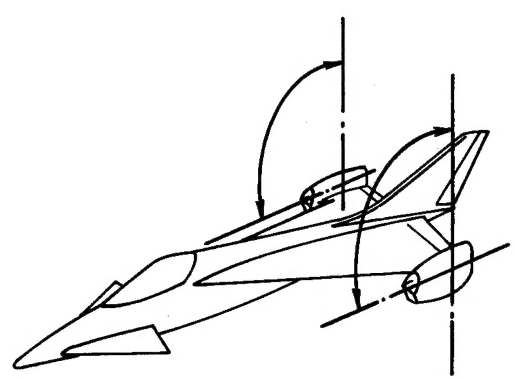

Fig. 4D - Tilting jet configuration

In regard to the space available for take-off and landing, consideration should be given to what is meant by the term unprepared when applied to a landing area. A truly unprepared area could be conceived of as meaning merely a clearing in the trees large enough to drop into vertically, conditions frequently encountered by helicopters on emergency missions. However, the term is loosely applied and frequently refers to areas that are only relatively less prepared than a long stretch of paved runway. Aircraft with high downwash velocities such as ducted fans and jet engines cannot operate off of certain surfaces such as dust covered, or even sodded soil continuously without damaging themselves or surrounding personnel. Thus, landing areas for such aircraft, even in the vertical take-off case, will require some type of ground surface stabilization, possibly even some type of landing pad or platform, a device made doubly necessary by the adverse ground effect associated with many of these machines.

It would appear that under battlefield conditions, ranging from guerrilla warfare to the tactical use of nuclear weapons, the only aircraft that could not perform the vast majority of their assigned tasks without VTOL capabilities would be assault transports and liaison or utility vehicles that might be used for light cargo, evacuation, or command purposes. These types of machines are intended to land in unprepared locations in the strictest sense of the word; any clearing large enough to accomodate their physical size being a potential landing field. Since physical size will form an important limitation on the number of landing areas available, both

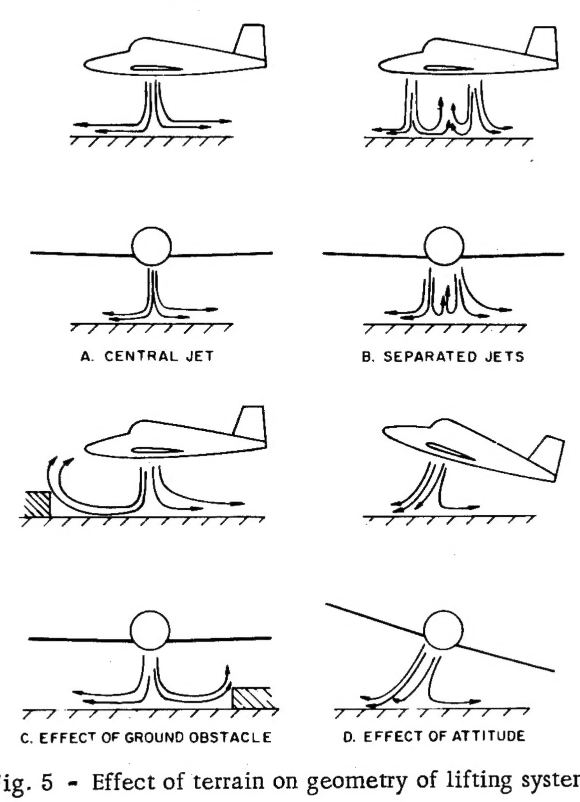

Fig. 5 - Effect of terrain on geometry of lifting system

of these types will be relatively small machines, the assault transport in all probability being no larger than the present C-123 and the utility machine only a four or five placer.

Under limited conditions, these missions could be conducted by helicopters. However, recent experience has shown that they are vulnerable to ground fire even from conventional weapons. Although the special ability of the helicopter to hover will gain for it a position in the tactical force for special types of service such as rescue, plane guard, flying cranes or even airborne traffic control, its use under conditions of anything less than absolute air superiority and against any but the lightest types of ground fire does not appear too promising in spite of the limited ground targets.

A more adaptable system, that is, one that will retain usefulness over a greater spectrum of types of war, would appear to be offered by VTOL machines having cruising flight speeds of at least 350-400 knots. To reduce front line logistic support problems, these machines will probably be of the propeller or fan driven type (high bypass ratio, turbofan engines may be attractive as well), thereby alleviating the fuel consumption associated with jet engines operating at low altitudes. Propellers will also reduce the disc loading and hence the ground erosion problem. Because of the hovering power installed, the cruise speeds should not be difficult to achieve and represent what many regard as the minimum for low altitude safety against even conventional ground defenses. Cruising range requirements could possibly be met by stopping one or more of the engines of a multi-power unit arrangement to utilize the improved specific fuel consumption obtained by operating the remaining engines near their maximum thrust.

Although the higher speeds of the VTOL machines would not protect them from advanced anti-aircraft missiles, they would certainly be less vulnerable than helicopters to rifle, machine gun, or light flack fire as they crossed more heavily defended areas. Actually, of course, both the hypothetical VTOL types pictured in Fig. 3 and the more conventional helicopters would derive most of their ability to survive in action by staying at minimum altitudes, reducing their exposure to enemy fire. Neither could be expected to survive long in face of strong hostile air forces, but the great speed advantage of the VTOL would make it a much more useful weapon under nuclear war conditions when the ability to con-

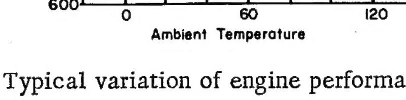

Fig. 6 - Typical variation of engine performance with inlet temperature

centrate rapidly in an area disrupted by nuclear blast, or to vacate an area where such a blast is threatened could be decisive.

The number of missions that can be conceived for such a VTOL utility aircraft and a similar, but larger assault transport, are innumerable. Carrying rockets and bombs, the utility machine would be a formidable close ground support vehicle in areas free of anti-aircraft missiles and enemy aircraft. Command, liaison, reconnaissance, and front line light cargo delivery or evacuation missions would all be possible. A previously inconceivable mobility could be achieved with the development of a cargo aircraft with a flexibility only slightly less than that of a truck, but possessed of a high speed ensuring deliveries in less than a tenth of truck time.

Although these machines must have the capability of achieving vertical flight to perform certain specific missions, much of their normal operational time will be spent as relatively conventional aircraft, landing on and taking off from completely adequate runways. For this reason, it would seem desirable to seek a solution for vertical flight that could perhaps be unshipped when not in use to minimize as much as possible the penalty in gross weight required for VTOL. Unless some way could be developed to remove an engine rapidly and without upsetting the balance of the aircraft, it would appear that the weight penalty of excess installed power and the drag associated with feathered propellers will have to be accepted. It may be possible, however, to minimize the weight associated with heavy wing tilting mechanisms, large flaps, and so on if more effective methods of deflecting the slipstreams can be devised.

For any type of relatively low speed aircraft to enjoy a reasonably long service life under battlefield conditions, control of the air is required. Even with complete control, it is unlikely that such low speed machines could penetrate deeply into an alerted enemy territory to strike at tactical targets. Under such circumstances, very high speed, probably just at tree top level, is the only method by which the attacker could hope to survive for long. There is thus a need for a very high speed tactical fighter-bomber.

Whether or not this machine, when fitted with appropriate weaponry, could serve as the air superiority fighter needed to establish and maintain the required control of the air is a matter of debate. Because of the difference in the operational altitude requirements for the two missions, it is likely that two different classes of machines would be required. Both would be basically supersonic fighters, and both would have to be designed to operate from small semiprepared runways, since it is likely that base mobility will have to be high.

The major differences between the two machines would arise from the high speed, low altitude requirement of the tactical fighter-bomber. Under such flight conditions, gust response becomes of major importance. To reduce this response to acceptable structural, instrument, and human tolerances, a very low slope of the lift curve is required. This can be achieved by nearly eliminating the wings. For short ranges and specialized missions, wingless bodies supported by direct jet lift at low speeds but largely by dynamic lift at the higher speeds may prove feasible. In general, however, the greater variety of missions arising from the wider range of lift to drag ratios obtained from the use of variable sweep would appear to dictate this solution.

The air superiority fighter, not having the same low altitude requirements, would not have to penalize its performance by employing the relatively heavy variable sweep arrangements, but could be designed to optimize its air to air weapons delivery capability.

Although both of these aircraft will have substantial range and loiter capabilities, their highest utilization will be realized if they are based in locations which represent compromises between the desirability of having them close to the scene of operations and the requirement that they be conveniently placed with regard to logistic service. Just supplying fuel for a squadron of such jets at an advanced base would be a formidable problem.

Because of these factors, it seems probable that finding adequate landing space will not form too great an operational problem for these machines. Although the number of available sites within any 100 sq mile area varies tremendously over the globe, there would seem to be enough to permit the take-off and landing lengths of these machines to be of the order of 2000-3000 ft. These lengths, although admittedly short by conventional jet fighter standards, should not be too difficult to achieve through the use of some vectored thrust considering the magnitude of the installed thrust required to meet the high speed specifications.

One of the requirements of the rapid striking tactical forces will be a flexible and highly adaptive logistic system. This will probably consist of many parts ranging from cargo aircraft to ships and trains. The aircraft elements of the system will probably consist of very large aircraft of great range capable of flying directly from their bases in the United States to a dispersal point possibly as much as 1000 miles from the battle field. Here the cargo would be transhipped to smaller aircraft to be flown closer to the scene of action. A second transhipping might then occur, the cargo being transferred to a machine that will carry it directly to the front.

It seems thoroughly impractical to attempt to develop V/STOL characteristics in the large cargo carriers. Range and load carrying capacity are of such importance that the disadvantage of having to tranship cargo upon arrival is accepted rather than sacrifice a single pound-mile. One can conceive of the VTOL assault transport being used as the dispersal vehicle by which the cargo is moved from the airport where delivered by the larger airplane to the battlefield area. Further distribution might then be performed by the utility craft.

Another area that must be examined for the possible use of V/STOL machines is the field of naval operations. The Marine Corps, operating in a manner analogous to that described above, would, under similar battle field conditions, require similar types of aircraft. By making use of the assault transports operating directly off of the troopships, beach heads would no longer have to be limited to the actual

beaches, but could be established many miles to the rear of the beach defenses. Since the assault transports could maintain a steady stream of supplies to the troops so landed, such a beach head would be much more substantial than one that would have to be supplied by parachute air drop.

Such operations can be only contemplated in face of an enemy having limited air and subsurface forces. In a strategic conflict, the existance of nuclear submarines, nuclear war heads, and reconnaissence satellites has rendered all surface naval forces obsolete. The growth of the technology supporting these sophisticated systems is beginning to limit the tactical capabilities of such naval forces. As the spread of technology equips more and more of the smaller nations with relatively sophisticated surface to surface weapons and the "volunteering" of satellite information or of submarines becomes an increasing possibility, the range of useful application of surface naval vessels continues to shrink. Although it would assuredly be a mistake to abandon the surface systems in existance, it would be just as great a mistake to expend vast amounts of time and money on attempting to develop defensive arrangements for an essentially indefensible system.

For the surface forces as presently constituted, there would appear to be little need to develop V/STOL aircraft for other than the marine assault operation. Present naval policy is to carry the required take-off and landing energies onboard ship in the form of catapults and arresting gear, thereby avoiding the necessity of penalizing the performance of the aircraft. The only areas in which more is required than the ability to slow down to levels where the landing and take-off energies can be handled by the shipboard installations are in rescue, ship to ship replenishment, plane guard, and antisubmarine warfare.

In all of these missions so much emphasis is placed on the ability to hover that the helicopter appears to be the reasonable solution. For the most part the distances to be covered are not great nor are the surface ships' speeds high, so there is little need to develop high speed systems to perform these tasks. The possible exception to this is the antisubmarine mission; but as long as this is restricted to sonar dipping not far from the float, the helicopter is an adequate answer.

The increased vulnerability of surface forces created by even such non-nuclear systems as the reconnaissance satellite and the relatively long range air to surface missile has created a large gap in the Navy's tactical capabilities. Although effective as a show of force if the enemy is not equipped with air or naval forces, the large carrier task force, so effective in World War II, could become a liability in the next war if the enemy could mount a substantial attack against it. Should such an attack be successful, the blow to national prestige and morale could be serious. It could, in fact, lead to retaliatory actions that might seriously jeopardize the possibilities of keeping the conflict localized.

To regain these tactical capabilities, many feel the Navy should take its ships under water. The Polaris submarines have demonstrated the effectiveness of such an approach to strategic systems. The highly streamlined hulls of the Albacore and her derivatives have produced vessels the tactical potentials of which have hardly been explored since attention has largely been limited to striking at enemy vessels either on or below the surface.

The major disadvantage of going under water is that while the submarine is unseen, it is also unseeing. With the exception of a Polaris type system in which a successful attack can be launched knowing only the positions of the launching submarine and the distant strategic target, tactical use of the weapon will involve locating and attacking far more elusive objects ranging from ships and planes to shore installations and mobile ground targets. Currently, the only methods by which a submarine can determine tactical targets are of limited range, be they visual, sonar, or radar. Technology has, however, advanced to the stage where it is not unreasonable to seek increases in tactical range through the coupling of airborne systems with subsurface systems. Such systems could be developed to perform both reconnaissance and strike missions. They might range from manned or unmanned aircraft, to missiles for attacking subsurface, surface, or airborne targets.

Since most of these systems are still little more than inventors' dreams, it is difficult to evaluate the role that V/STOL aircraft may play. To be effective, the weapon should possess as nearly an all weather capability as possible; thus, although the concept of a submergible aircraft carrier that comes to the surface to launch and recover aircraft may be the most expedient manner of crossing the liquid interface, operations might be severely limited by sea state. Missiles and aircraft which can be launched from below the surface, cross the interface, travel through the air and return to beneath the waves are also distinct possibilities although technically more difficult. It is not unlikely that V/STOL capabilities may prove useful in such operations.

RESEARCH AND DEVELOPMENTAL PROBLEMS

Although, in an unclassified paper one has to be vague, a fact which frequently works for an author making his thoughts appear more profound than they actually are, from the preceeding discussion it is hoped that some of the challenges confronting the designer of V/STOL military aircraft have begun to emerge.

A V/STOL weapon system will be tactical in nature. To have a wide range of application on the battlefield, at least three general types of machines need to be developed: a utility aircraft, an assault transport, and a tactical fighter-bomber. A STOL air superiority fighter might represent a fourth type. Only the utility aircraft and the assault transport seem to present a true VTOL mission requirement, STOL performance being acceptable for the other types.

The picture does not appear nearly so clear cut in the case of naval operations because of the extremely unsettled and unpredictable state of affairs created by the limitations of the tactical capabilities of surface fleets. It does appear likely, however, that true VTOL capabilities will be de-

manded by a number of weapon systems envisioned as coupling submarines and aircraft.

A sufficient amount of research has now been performed to permit the statement that there are no major technical obstacles blocking the development of the entire spectrum of aircraft envisioned. However, much detailed research and development remains to be performed before they become realities.

Continuing research into the nature of the aerodynamic phenomena associated with speeds below that at which wing supported flight is possible is necessary to provide the information required to ensure adequate stability and control. Further studies of methods of achieving such low speed flight are required to assure the development of the highest efficiency for each type of mission. As an example, the tilt wing and rotatable fan have been shown to be workable solutions to the VTOL performance of relatively small, low performance machines. Such solutions could be used to produce a satisfactory liaison aircraft; but as demonstrated by the larger assault transport machines currently under construction, the problems associated with tilting the wings of a large airplane, or manufacturing large ducts for fans, are formidable indeed. As a result, alternate solutions such as combinations of moderate wing tilt, flaps and possibly boundary layer control or hybrid designs utilizing ejectors or fans in the wing are being examined.

Much work remains to be done in the development of engines and propellers. Engines may be required to function through large angles of tilt and must be modified to do so in a trouble free manner for protracted periods. The power requirements for many machines vary so much between takeoff and level flight that some thought might be given to developing an engine containing within itself both high load and cruising turbines. The subject of cross coupling either by mechanical or thermodynamic means must also be pressed so that a power failure in low speed flight need not be catastrophic. Propellers designed for high static thrust conditions, but still retaining reasonable forward flight characteristics, are an absolute necessity to the success of many types of these aircraft.

Obviously further research into the unique characteristics of the high speed configurations required by the fighter machines will be required before reasonable short field performance can be assured. Particular attention should be paid to the deleterious effects produced on most of the devices currently under consideration by the proximity of the ground.

Significant as are all of these areas of research, they are almost routine developments compared to the work that must be done on the problem of developing systems that can operate both above and below the surface of the water. Studies must be conducted to determine the best methods of launching and recovering vehicles through the interface under a wide range of sea state conditions.

The future of V/STOL aircraft actually depends upon a policy decision that must be made at the highest level of the Department of Defense. In order to realize any of their potentials, the development of these aircraft must be backed by the anticipation of reasonable production. Before any such production can be contemplated, the authorities responsible for weapons policy must be convinced that these systems will provide the greatest potential return for each defense dollar spent. Before they can be so convinced, some demonstration of the operational capabilities of these systems must be provided.

So the loop closes and progress stalls. Much of the basic exploratory work on the aerodynamic and mechanical aspects of the various forms of V/STOL aircraft is complete. Most of the remaining unknowns lie in the grey area of operational development, the work that will lead to the eventual formulation of specifications directed at procurement for service use.

Fortunately, there are signs of progress, indications that an awareness of the potentials of such weapon systems is growing. In this country, the triservice tilt-wing, and the Navy's tilting duct machines, are attempts to enter the operational development area. Even greater progress has been achieved in Europe where the success of Britain's SC-1 and P-1127 have been responsible for the enunciation of the set of specifications for a NATO, VTOL fighter. Although these specifications are heavily colored by the geographical location and operational climate of Western Europe, they cannot help but have an influence on the eventual development of our own military systems.

Thus, although when compared to the massive military systems such as the ballistic missiles that have attracted practically all of the developmental attention for the past decade, the development of V/STOL aircraft has been slow and halting, it does at least appear to be accelerating. The remaining problems, formidable as they may be, are within the state-of-the-art. With the gradual awakening of an awareness of the potentials of such tactical weapon systems, the realization that although they are no panacea they have a real place in the national arsenal, it seems certain that this development will continue at an increasing pace so that the next 5 years will see the introduction of at least rudimentary V/STOL aircraft into service use.